CALCULATIONS FOR:

Waterbury, VT 089-2 (43) Re-Advertised

529.2, Partial Removal of Structure (Bridge 46S and 46N)
Demolition of Existing Bridge Deck

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Prepared by:

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2-13-15

References:

Design of Concrete Structures, 12th ed., 1997, Arthur Nilson
LRFD Steel Design, 2nd ed., 1999, William Segui
Manual of Steel Construction, Load & Resistance Factor Design, 2nd ed., 1998, AISC

Scope of Structure Removal:

Demolition is to proceed in a single sequence, beginning with the sawcutting and removal of the existing deck by excavator. The concrete diaphragms are to be removed by sawcutting the portion between girders and picking with excavator or crane, and hand chipping the remainder onto the subdecking. Provide temporary cross-bracing for girders at piers after removing concrete diaphragms. Subdecking, as previously submitted, provides debris protection and fall protection. Girder jacking and replacement of existing bearings is discussed in another submittal.

Worker Protection for Demolition:

The deck is to be removed by sawcutting, with removal of slab sections by excavator. Typically, fall protection will be provided by subdecking between girders and on brackets at overhangs. See the previously submitted subdecking design for details.

If fall protection is not provided by subdecking, workers on the deck will either be protected from falls by the existing bridge rail, or cable safety lines connected to fall protection posts, guardrail posts, or concrete deadmen. Workers using safety cable will use compliant harnesses and shock-absorbing lanyards or self-retracting lifelines. To limit worker exposure to falls, the interior sawcuts are to be made prior to removing overhang sections of deck and the associated sections of bridge rail. The longitudinal sawcut on the outside girder will be made last, with the excavator lifting each piece as it is removed, and the sawcut crew tied off if harnesses are required. After removing the overhangs, the center slab sections are removed.

A control line set back 12' and safety cable, or wood guardrail system, will be installed at the existing abutment, where proximity to a fall hazard exists.

Public Protection and Environmental Protection for Demolition:

Subdecking between girders and at overhangs is located over all roads and sidewalks to provide protection against falling debris. A plastic liner will be provided over the road/sidewalk and stream and wetland areas during sawcutting, to prevent cutting slurry from spilling onto these areas.

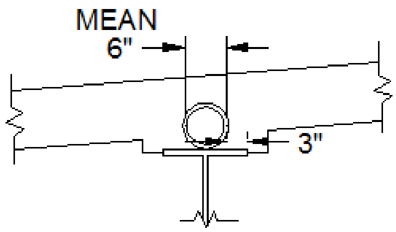
Equipment in use during Deck Demolition Operations:

Equipment to be used for deck demolition operation includes the following:
Concrete saws and related equipment by a subcontractor
Caterpillar 324 / 329E excavator with "slab-crab" type attachment
Semi Tractor with 48' flatbed trailer
Various cranes for man-basket and scale pan

Part 1: Checks of Concrete Deck

Removal of Bridge Deck:

Check the location of shear studs or spirals before sawcutting, by chipping out a small area at the leading edge abutment. Shear spirals with 6" mean diameter are anticipated, with sawcuts to be made a minimum 1.5" (3" typ.) from the edge of girder.



Prior to deck removal, remove all pavement and sawcut the lateral and longitudinal lines at the interior girders, followed by longitudinal cuts at overhangs. Once any fall protection measures are in place on the deck, the overhangs in the area of the day's cuts will be removed. This is to be accomplished by first chipping out the coping at the lateral cut location, cutting or removing the bridge rail, and then sawcutting longitudinally along the outside girder, with the overhang section supported by excavator or crane, hooked onto the slab section using the existing guardrail anchor bolts.

Assume 8' long overhang section. Weight = 4.32 SF *150 pcf *8' = 5,184 lb = 5.2 k
¾" anchor bolt, assumed A307, has:
allowable tensile load = 0.6*0.75*45 ksi*0.44 in2 = 8.9 k/bolt
allowable shear load = 0.6*0.75*24 ksi * 0.44 in2 = 4.7 k/bolt
Need to connect to a minimum of 2 bolts per 8' slab section.
Pick using a minimum of 4 existing anchor bolts, either 2 ea. at 2 post locations, or 4 ea. at a single post.

Check cutoff overhang loading on subdecking vs subdecking design:

Overhang subdecking design is for 210 psf * 2.5' width + 1000 lb / 4' spacing = 775 lb/ft total concrete and screed loading. Ignore that about ½ the load will be resting on the edge of girder flange instead of subdecking

Applied overhang load during demolition = 2' wide beyond girder * 2' high * 150 pcf + 100 lb worker = **700 lb < 775 lb. Okay to let concrete deck+curb at overhangs rest on overhang subdecking**.

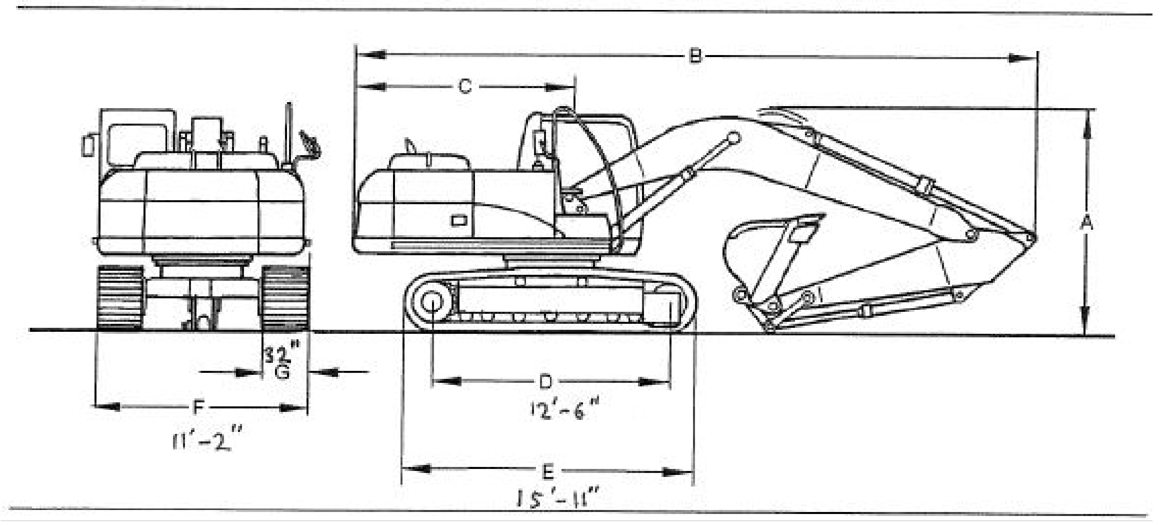
After removal of the overhangs, the interior slab sections will be removed by the excavator with a "slab crab" attachment, and loaded onto a truck for transportation to the disposal site. The interior bay slabs will be lifted out individually. The deck slabs and other concrete and rebar will be disposed of off-site.

Concrete left on girders at shear connectors will be chipped into a scale pan or similar device to catch the debris.

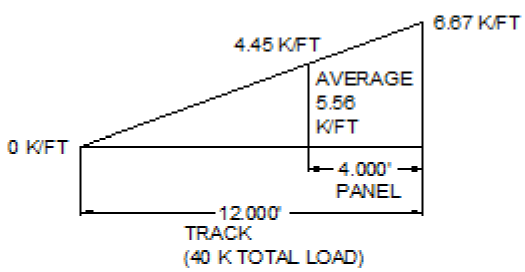
Structural Checks for Deck Removal:

Of concern during demolition is the capacity of the cut deck panels, to withstand the loads imposed during removal operations. The loads consist of deck panel self-weight, and either the CAT 324 excavator track or truck tires on any given panel.

Excavator Loading on Slab:



The excavator load is 55k gross weight + 1k to swap the slab crab for bucket + 5k for a panel being hoisted = 61 k * 1.3 impact = 79 k. This load is taken as distributed equally between the tracks in a triangular distribution. Load per track = 79k/2 = 40 k. If excavator is in full contact with deck, the load can be taken as triangular in the worst case, and take the max loading on an assumed 4' wide panel section.



The track is 2.67' wide, so the max bearing pressure over the 4' panel is 6.67 k/ft / 2.67' = **2.50 ksf, as long as the excavator is kept stable with the tracks in full contact with the deck.**

Truck Loading on Slab:

A truck axle load is taken as 20k, from records of permitted trucks. The load per set of wheels is 24k/2 = 12k, distributed among dual wheels, with a contact patch 13"x2 = 2.17' wide, by 12" long. The bearing pressure is 12 k / (2.17' * 1') = **5.5 ksf**

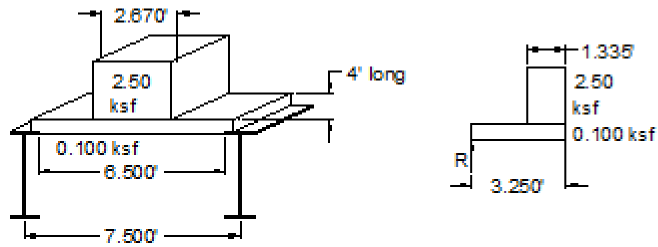
Slab Deadload:

The slab is 7.5", carry 8" thick, so has loading of 150 pcf * 8/12' = 0.100 ksf

Check of Slab in Bending:

The slabs are cut into rectangles, with sawcuts 3” from the edge of the existing girders, and transversely every 8’ +/-. The slabs span 6.5’ between girder flanges. Check the capacity of half the assumed panel width, or a 4’ wide panel.

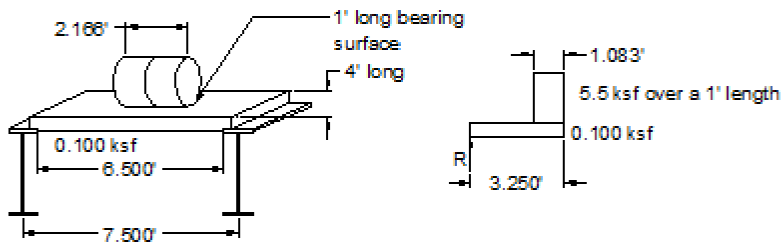
Bending from excavator track load, using the maximum bearing pressure:



Mmax = (2.50 ksf * 4’) * 1.335’ * 2.582’ excavator + (0.100 ksf * 4’) *3.25’*1.625’ deck

Mmax = 36.6 k-ft

Bending from truck wheel load:



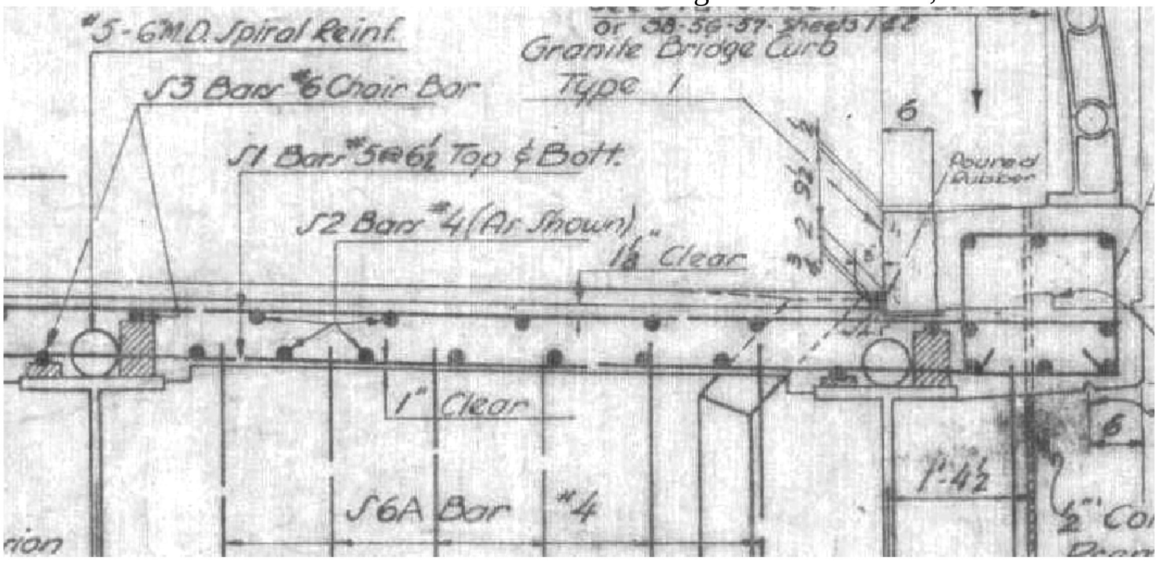
Mmax = (5.5 ksf * 1’) * 1.083’ * 2.709’ truckwheel + (0.100 ksf * 4’) *3.25’*1.625’ deck

Mmax = 18.2 k-ft

The excavator produces the greater bending moment, take

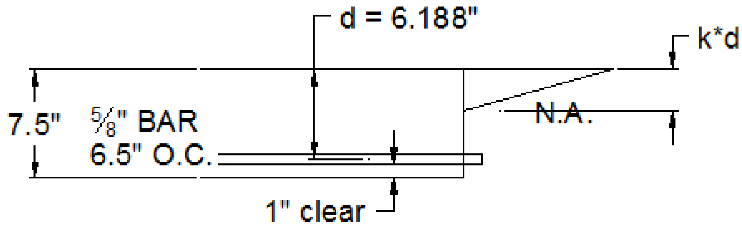
Mmax = 36.6 k-ft = 439 k-in for a 4’ panel section.

Use the cracked deck section to find allowable bending. For the width b, use 48".



(from existing plans)

At high-moment regions of slab, bot. mat is #6 bar @ 5" o.c. Ignore top mat.



The following procedure for bending and shear is from Design of Concrete Structures, section 3.3:

Set f_c*A_c and f_s*A_s to have equal moments about N.A.:

$\frac{b*(kd)^2}{2} - n*A_s*(d-kd) = 0$; solve for kd:

n = 8.0, b = 48", d = 6.188", A_s = 0.31 in^2 per #5 bar * 7.38 bars (at 6.5" centers in 48")

A_s = 2.288 in^2

Solving equation graphically, kd = 1.824"

find f_s and f_c, by taking moments about the other member.

for f_s:

ΣM_c = A_s * f_s * j*d; limit ΣM_c to the applied moment.

j = 1 – k/3;

k = $\sqrt{(pn)^2 + 2*pn} - pn$

pn = $^{As}/_{b*d} * 8.0$ = 2.288 in^2 / (48"*6.188") * 8.0 = 0.0616

k = √(0.0616^2 + 2*0.0616) – 0.0616

k = 0.295

j = 1 – 0.295/3 = **0.902 = j**

ΣM_c = M_{max} of 439 k-in = 2.288 in^2 * f_s * 0.902 * 6.188"; solve for f_s

f_s = 34.4 ksi, vs 33 ksi min. yield, and 55 ksi ultimate, assumed for reinforcing prior to 1950s. 34.4/33 = 104% of yield, 34.4/55 = 63% of ultimate (60% is adequate; ok). Since bending (with impact) is slightly past the yield point, excavator tracks are to be located over or adjacent to girder lines when possible during slab removal to reduce bending stress. Bending stress is allowable vs. ultimate tensile strength, and yielding of the rebar is allowable for demolition.

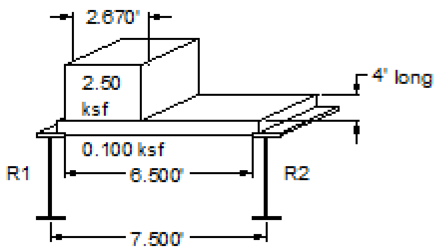
ASTM Spec, Steel Type	Years	Grade 33 (Structural)	
		Min. Yield (ksi)	Min. Tensile (ksi)
A15, Billet	1911-1966	33	55

See shear calculations for check of bending during this loading condition. If excavator track is located at center span, it may result in reinforcement yielding, producing an evident deflection of slab.

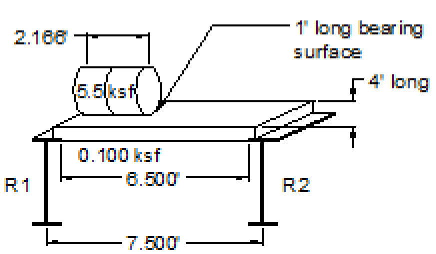
for f_c:
$\Sigma M_s = M_{max}$ of 439 k-in = $f_c / 2 * b*k*d^2*j = f_c / 2 * 48" * 0.295 * 6.188^2 \text{ in}^2 * 0.902$;
solve for f_c
f_c = 1.8 ksi, vs 3 ksi concrete, 60% of ultimate, ok; concrete stress is proportionally less than steel stress.
Steel FoS is slightly critical: under-reinforced, which is preferable.

Check Concrete Deck Shear at Stringer:

The max shear will occur if the excavator or wheel load is right next to the beam.



Excavator shear load, sum moments about R2:
R1 * 6.5' = (2.50 ksf*4') * 2.67' * 5.165' + (0.100 ksf * 4') * 6.5' * 3.25'
R1 = max shear = 22.5 k excavator



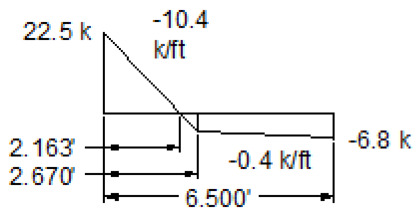
Truck shear load, sum moments about R2:
R1 * 6.5' = (5.5 ksf * 1') * 2.166' * 5.417 + (0.100 ksf * 4') * 6.5'* 3.25'
R1 = max shear = 11.2 k wheel

The excavator produces the greatest shear, so
Vmax = 22.5 k.

$v_{max} = V_{max} / (b*d)$ = 22.5 k / (48”*6.188”) (not $v_{max} = VQ / Ib$ normally used)
v_{max} = 0.076 ksi = 76 psi

find v_{cr} based on proportion of moment and shear during the maximum shear condition:
At Vmax for the excavator track above, find Mmax:

Excavator + concrete load = 2.50 ksf * 4’ + 0.100 ksf * 4’ = 10.4 k/ft
Concrete load = 0.100 ksf * 4’ = 0.4 k/ft



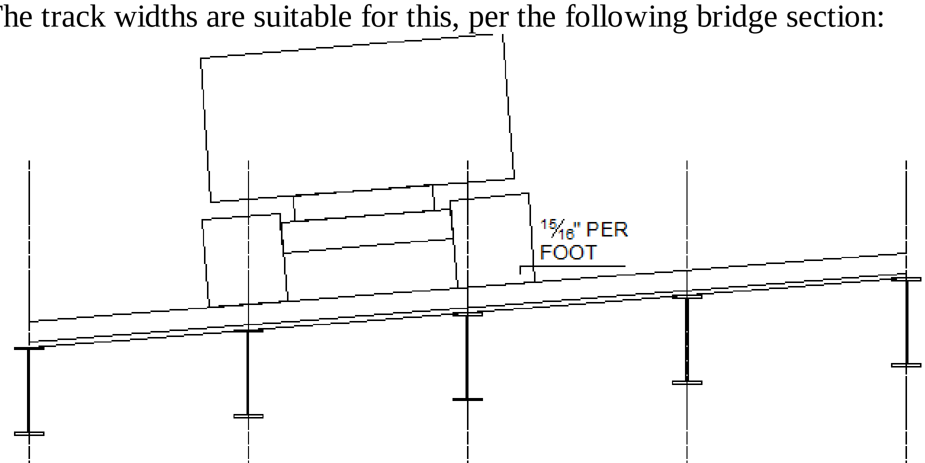
Mmax at 2.16’ from R1.
Mmax = 10.4 k/ft * 2.16’ * 2.16’/2 = 24.26 k-ft = 291 k-in (448/291 = 1.5, ok.)

Per <u>Design of Concrete Structures</u>, section 3.3:

$v_{cr} = 1.9*\sqrt{f'_c} + 2500*\rho*V*d/M < 3.5\sqrt{f'_c}$ where
include bottom and top mat of rebar, total 3 ea #5 bar at 10” o.c.;
A_s = 0.31 in^2 * 2 layers * 7.3 ea. bars (@ 6.5” over 48” wide slab) = 4.526 in^2
ρ = 4.526 in^2 / (6.188”*48”) = 0.0152
f'_c = 3000 psi
$3.5\sqrt{f'_c}$ = 192 psi

$v_{cr} = 1.9*\sqrt{3000}$ + 2500 * 0.0152 * 22,500 lb * 6.188” / 291,000 lb-in
v_{cr} = 122 psi < 192 psi, so use **v_{cr} = 122 psi**.

v_{max} = 76 psi, **FoS = 122/76 = 1.6, concrete shear is ok**. Note tracks should typically be located so they are at least partially over a girder, which will reduce shear stress. The track widths are suitable for this, per the following bridge section:



Check bearing capacity of slab on edge of girder flange:

The maximum bearing load on the slab edge is equal to the max shear force figured above = **22.5 k** for a 4' long slab section.

The allowable bearing pressure on the concrete slab is conventionally limited to 1000 psi. For a 4' long contact area, the required width is 22.5 k / (48" * L) = 1.00 ksi The minimum L = 0.5" * 1.5 factor of safety = 0.75" bearing width required. **Say the minimum bearing width is 1.5" for sawcutting panels, 3" typ based on shear spiral layout. Prior to cutting, investigate the locations of the shear studs, to lay out and cut as close to the centerline of girder as possible.**

Part 2: Checks of Steel Superstructure

See the attached girder stability calculations from Calderwood Engineering. Below, integrate these calculations into the demolition sequence.

Equipment is to be located in separate lanes on the bridge, with the excavator loading a flatbed trailer with slab sections. The trailer is to pull up alongside the excavator. **Keep 7.5' separation from center of track to center of wheel loading (1 girder bay)**. **Limit equipment to 5 mph speeds.**

The steel calculations show (p. 3-4)

Max DF for the tractor trailer = 0.6 > ½ the weight of the vehicle weight

Max DF for the excavator = 0.433 approx. < ½ the excavator weight, but trailer loads generally govern.

Equipment loads may be placed over or adjacent to a girder.
Loads were checked for a **min. distance of 2' to the curb.**

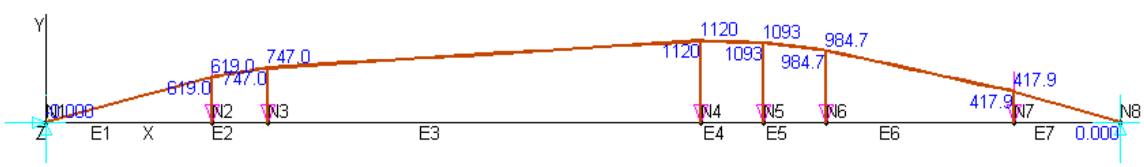
The steel calculations find the girders are overstressed due to tractor-trailer load in certain situations (p. 9, 20, 31). To alleviate this, reduce the axle loading on the tractor-trailer. Max overstress = 1.137 (p. 31).

Check G4: $M_{uG4} = DF*M_{Utruck} + M_{deadint} = 0.6 * 1260$ k-ft + 766.831 k-ft

$M_{uG4} = 1522.831$ k-ft

Reduce tractor-trailer axle loadings from 24 k to 20 k, and 20 k to 18 k.

From p. 28, re-calc M_{Utruck}. $M_{Utruck} = 1120$ k-ft



$M_{uG4} = 1439$ k-ft = 17,268 k-in

$f_{bG4} = 17{,}268$ k-in / 737.765 in3 = 23.4 ksi

Overstress = (23.4 – 21.78)/21.78 = 0.074 = **7.4% overstress < 10% over, ok with reduced axle loads.**

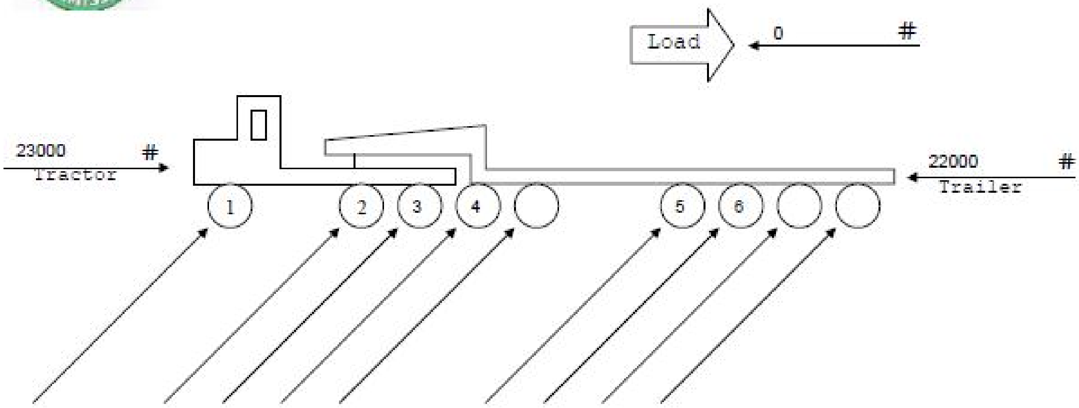
Check trailer loading with specified axle loads:

Clear

Print

AXLE WEIGHT WORK SHEET

Estimating Weight Per Axle



Trailer & Load Information & Calculations

Load Weight -- 129500 #

Trailer Weight------------------------------------ 22000 #

Total Weight of Load & Trailer------------------ 22000 #

Divide the Total Weight of Load & Trailer by the Total Number of Tandem Axles.
Definition: Tandem Axles (Load Bearing), Axles 2 through 9+.

Load & Trailer, Total Weight Per Tandem Axle -- 4400 # EA.

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Truck/Tractor Information & Calculations

Total Tractor Weight------------------------------- 23000 #

Divide the Weight Between the Steering Axle (Axle #1), and the Tandem Axles (Axles #2-??)
Calculate the Weight of Axle #1 by estimating 70% of the Total Tractor Weight.

Tractor Weight Axle #1 ---------------------------- 14000 #

Divide the Remaining Tractor Weight by the Total Number of Tractor Tandem Axles.
Definition: Load Bearing, Drive Axles & Air Axles Affixed to the Tractor Unit.

Axle#2 3000 # Axle#3 -- 3000 # Axle#4 -- 3000 # Axle# ____ -- ____ #

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To the Tractor Tandem Axle Weights Above, Add the Weight Per Axle for the Load & Trailer.

Axle#2 4400 # Axle#3 -- 4400 # Axle#4 -- 4400 # Axle# ____ -- ____ #

Add -- 3000 # 3000 # 3000 # ____ #

The Total Tractor Tandem Axle Estimated Weight is the Combination, Tractor, Trailer & Load.

Axle#2 7400 # Axle#3 -- 7400 # Axle#4 -- 7400 # Axle# ____ -- ____ #

Axles 2, 3, 4: 7.4 k empty, net capacity = (18 k – 7.4 k) * 3 axles = 31.8 k

Axles 5, 6: 4.4 k empty, net capacity = (20 k – 4.4 k) * 2 axles = 31.2 k

Net trailer capacity = 31.8 k + 31.2 k = 63 k

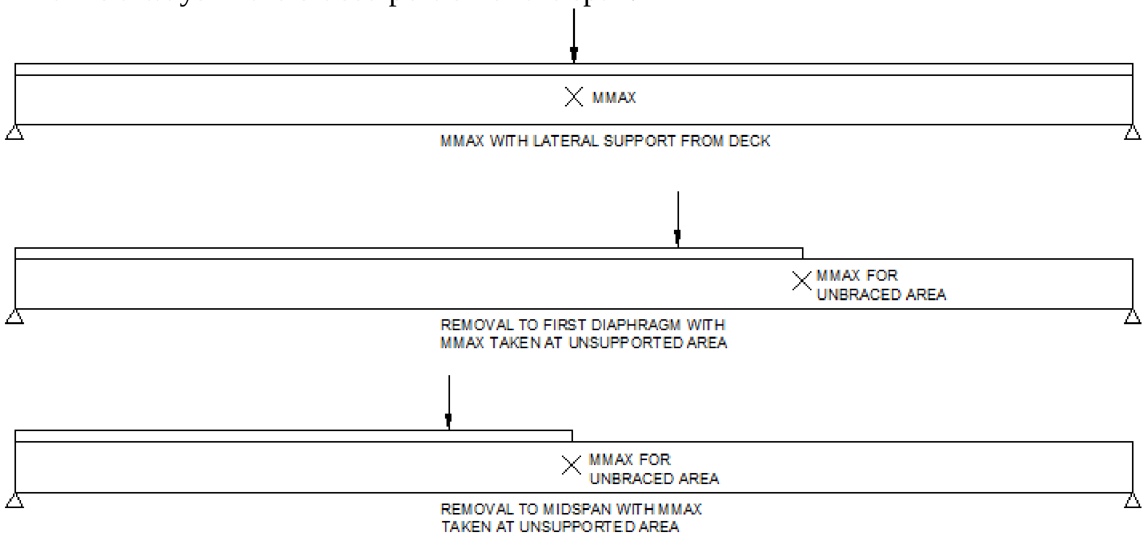
Typ deck slabs weigh 150 pcf * 8"/12 * 7.5' = 750 lb/ft = 0.75 k/ft

63 k / 0.75 k/ft = 84' of deck slabs on trailer.

Limit trailer load to 84 bay-feet of slab sections (approx. 2 layers on a 48' trailer)

Start deck removal from Pier 3, with separate removal operations toward each abutment. Per the structural steel drawings, this will avoid loading the girders where the distances between diaphragms are large, except when the deck is still in place. See the attached dimensions taken from the existing bridge plans. The North end of span 1-3, and the South end of span 4-5, will either have deck panels in place when loaded, or will be unloaded when the deck is being removed. This produces the values for Lb shown in the steel calculations.

Bending is checked in the steel calculations under full deck load, with deck removal to the first diaphragm, and deck removal to midspan. As noted in the calculations, Mmax is calculated for the unbraced girders as the point where the deck is removed, as the actual Mmax is always in the braced portion of the span.



At girder ends, Lb is taken as the distance from end of girder to first diaphragm. Remove the concrete end diaphragm after the first 10’ of deck, and install temporary diaphragms. Diaphragms must resist 2% of the compressive load from bending. This load is greatest for the heaviest girder. Check W36x300 for bending with deck removed to first diaphragm, for max bending near end of girder (p. 51):
Mmax = 1173.6 k-ft; compressive component = 1173.6 / 2 = 587 k-ft = 7042 k-in.
Take moment arm as 18” – 1.33” (y_p for WT18x150) = 16.67”
Compressive load to resist = 0.02 * 7042 k-in / 16.67” = **8.5 k X-bracing load**

Provide substantial timber X-bracing to span between girders with wire ropes in tension between girder flanges.

Add 1/2 transverse load (2 members in X-brace):
wind loads = 0.4 k/ft * 22’ between braces = 8.8 k / 2 = 4.4 k

Total brace load = 8.5 + 4.4 = 12.9 k; say 15 k.
If X-brace member is at 30 degrees (max) from horizontal, load on brace = 15 k / cos30
=17.3 k compressive load.

For timber (oak, SPF, or similar) allowable compressive stress parallel to grain = 1100 psi * 1.6 for a short duration load = 1,760 psi = 1.7 ksi.
Required timber area = 17.3 k / 1.7 ksi = **10.2 in^2 required**
Use a 3x6 rough-sawn timber or equivalent for X-braces (18 in^2 area).

Cables are to resist 15 k load.

1/2" cable has break strength = 24 k.

allowable load = 24/2 = 12k; require a double cable with plate-type hook as cross-bracing. Install the timber x-braces in line with cable braces, to resist the cable pull.

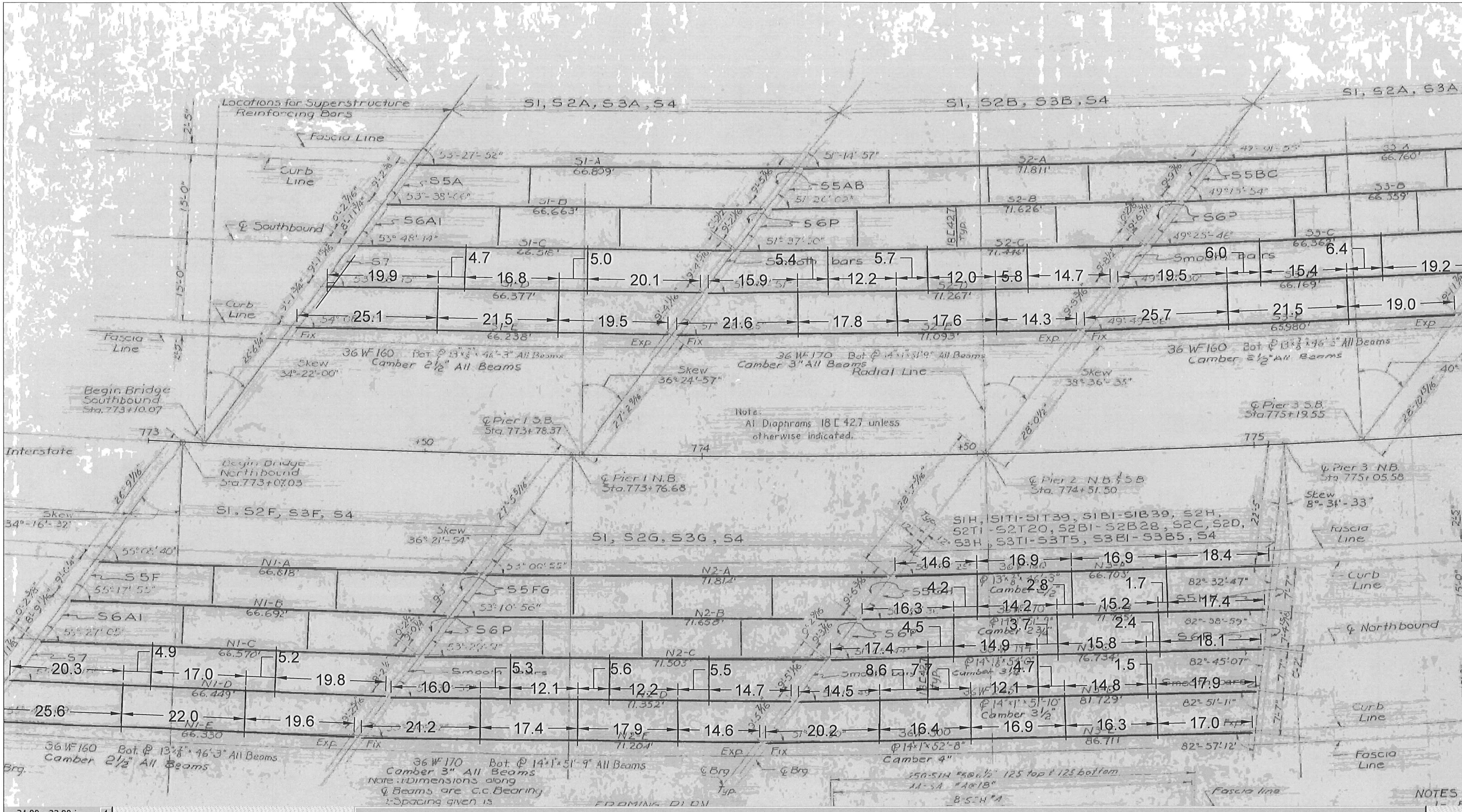
Girder bearing:
The girder has bearing stiffeners. Bearing is not a concern.

Girder Shear:
Compare loading to shear produced by HS-20 loading. Check W36x160, which has the proportionally smallest shear capacity. From HS-20 load tables, for 67' span, shear per lane load = 62.1 k.
Divide lane load among 2 girders: LL Vmax = 31 k per girder, no impact.

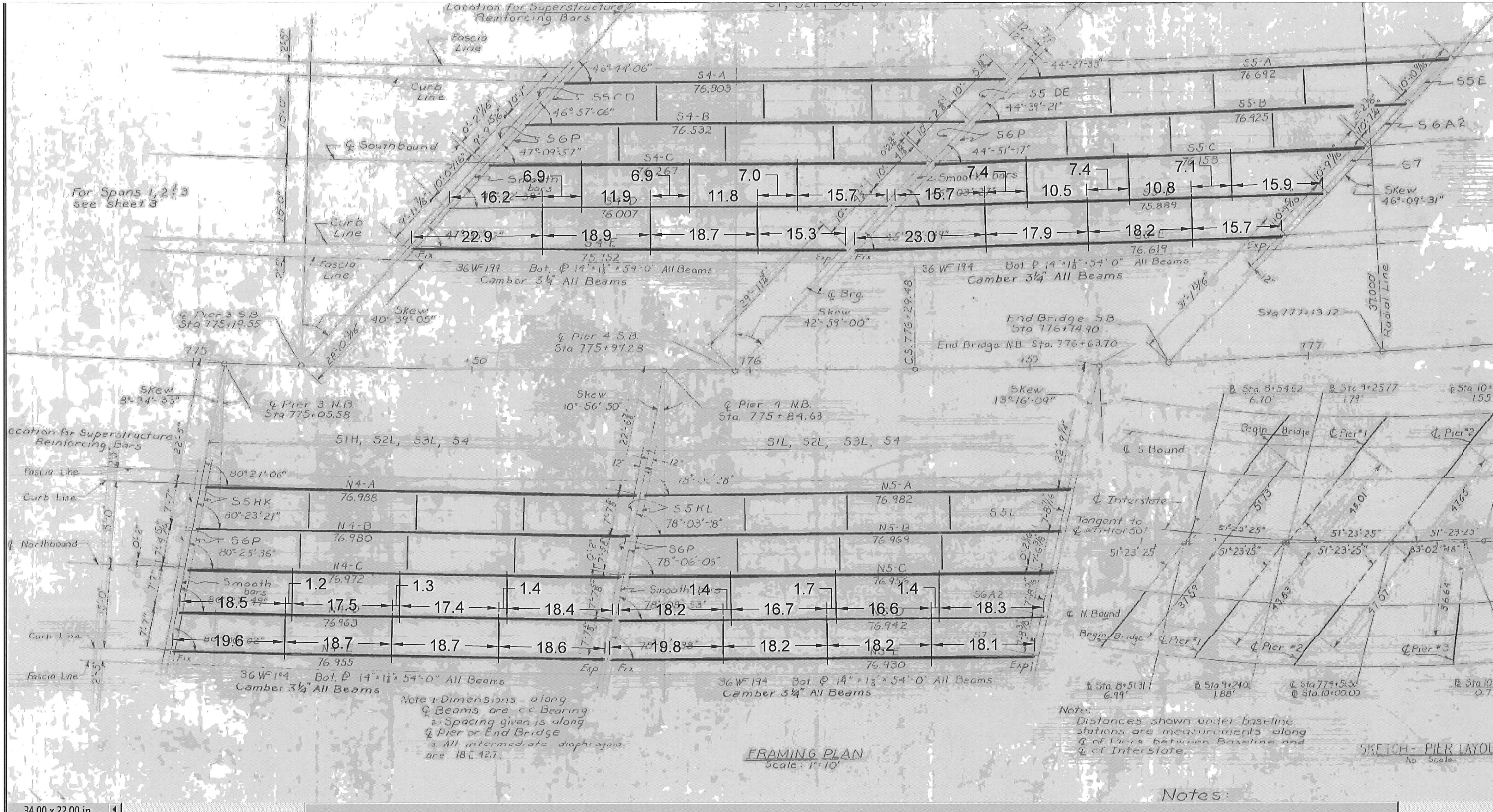
Vmax from live load during jacking = 56 k excavator * 0.5 DF = 28 k per girder
Tractor-trailer, with rear wheels at the bearing, Vmax = 68.41 k
68.41 k * 0.6 DF = 41 k per girder, controls over excavator.
DL on girder:
Steel = 0.2 k/ft * 1.05 = 0.21 k/ft
Deck = wext = 1 k/ft
Total shear = 41 k + 1.21 k/ft*67'/2 = 81.6 k shear force
Allowable shear load on girder:

h/tw = 32.125"/0.65" = 49.4; 418/√36 ksi = 69.7 > 49.4, no web instability.
Vallow = 0.6 * Φ * Vn = 0.6*0.9*0.6*36 ksi*(0.65"*32.125") = 243 k
Allowable shear stress is >> applied shear; shear is ok.

<u>Appendix:</u>
Steel diaphragm dimensions from existing steel drawings, 2 sheets
Calderwood Engineering steel girder calculations, dated 2-4-2015, 110 pp.



	SHEET 1 OF 2
REV:	TITLE: 46S/46N DIAPHRAGM LAYOUT
	PROJECT: WATERBURY IM 089-2 (43)
	SCALE: 1" = 16' / DATE: JAN. 7, 2015
	BECK & BELLUCCI, INC. FRANKLIN, NEW HAMPSHIRE



SHEET 2 OF 2

TITLE:	46S/46N DIAPHRAGM LAYOUT
PROJECT:	WATERBURY IM 089-2 (43)
SCALE: 1" = 16'	DATE: JAN. 7, 2015
REV:	

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